Invited Commentary

The Evolution of TENS

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Abstract: Since the Egyptian era, various forms of electricity have been used to relieve pain. Natural sources of electricity were replaced by small battery-operated stimulators in the 1800s, but a long transition period ensued before the theoretical basis of "electroanalgesia" was published. Transcutaneous electrical nerve stimulation (TENS) devices are currently used in many areas of health care practice for both analgesic and non-analgesic applications. Despite the popularity of this electrotherapeutic modality, clinical research has been equivocal. Several systematic reviews of the effectiveness of TENS for a range of conditions have been published with largely negative findings. However, the quality of the published research should be considered before drawing any conclusions about this device. This paper provides an overview of the evolution of TENS from the early stages and comments on the problems with clinical research studies to date. The clinical efficacy of TENS will remain ambiguous until sufficient numbers of high-quality, randomized, controlled clinical trials are published.

Key words: transcutaneous electrical nerve stimulation, pain management

Introduction

The use of electricity for pain management can be traced back to the time of the ancient Egyptians. Different types of electrogenic fish were used to apply electric shocks to the body, thereby numbing the area of pain. The development of the battery and induction coil added some sophistication to the concept of electroanalgesia, and by the end of the 1800s, early prototypes of the modern electrical stimulator were available. However, the theory behind electroanalgesia did not emerge until the 1960s, when Melzack and Wall published their gate control theory [1]. The basic premise of this theory was that stimulation of large-diameter afferents could modulate the volume of nociceptive signals in small-diameter afferents.

Within a few years, clinical studies emerged to support this theory. Wall and Sweet first demonstrated that high-frequency percutaneous electrical stimulation reduced chronic neurogenic pain [2]. Shortly after, Meyer and Fields were among the first to report the success of transcutaneous electrical nerve stimulation (TENS) for the relief of chronic pain [3]. TENS involves the application of low-voltage electrical currents to the skin via surface electrodes. Technological advances have changed both the appearance and function of TENS units since the early versions. Standard features include variable parameter ranges, timer, belt clip to enable use while mobile, and a compliance monitor so the clinician can monitor patient use. Self-adhesive electrodes are widely available in a range of shapes and sizes, and have generally replaced the original carbon rubber electrode and gel application. Although TENS is primarily used for pain relief, it has several non-analgesic applications, including the promotion of wound healing [4] and the relief of emesis [5].

Stimulation Parameters

The characteristics or stimulation parameters of an electrical current determine the resultant physiological effect. Frequency, intensity and pulse duration can be manipulated on a TENS unit to produce the two most

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common modes of TENS, conventional and acupuncture-like TENS.

Conventional TENS

This is the most commonly used mode of TENS. The stimulation parameters are a low intensity, a high frequency, typically above 100 Hz, and a short pulse duration (50–80 μs). This combination of parameters stimulates Group II nerve fibres, thus producing a sensation of comfortable paraesthesia with no muscle contraction. As Group II fibres are stimulated, this TENS mode is believed to achieve analgesia primarily by spinal segmental mechanisms [6].

Acupuncture-like TENS

The parameters for acupuncture-like TENS include a low frequency (usually 1–4 Hz), a high intensity (high enough to produce visible muscle contractions) and a long pulse duration (~200 μs). It has been suggested that acupuncture-like TENS primarily stimulates small motor fibres and that this indirectly initiates activity in small-diameter afferents from the muscle spindles [7]. As the mechanism of pain relief associated with this TENS mode requires afferent signals from muscle receptors, the electrodes should be positioned to produce visible muscle contractions, e.g. over a myotome related to the painful area. Paraesthesia and muscle contraction (twitching) are experienced with this TENS mode.

It was originally believed that acupuncture-like TENS operated through the release of endogenous opioids via a supraspinal mechanism. However, recent animal studies by Kalra et al suggest that specific opioid receptors are activated by different frequencies of TENS. The data from these studies indicate that low-frequency TENS activates μ-opioid receptors and high-frequency TENS activates δ-opioid receptors [8].

TENS Research

A range of animal studies has been used to investigate parameter manipulation and also the neurobiological mechanisms underlying the effects of TENS [9]. For example, in an animal model of knee joint inflammation, secondary hyperalgesia was reversed completely by either low-frequency (4 Hz) or high-frequency (100 Hz) TENS at sensory intensities [10]. In contrast, in a similar animal model, high-frequency TENS only partially reduced primary hyperalgesia and low-frequency TENS was ineffective [11]. Ideally, results from studies utilizing animal models of pain should be replicated in human populations to provide a clear progression for some of the theories that have emerged.

Early TENS clinical research tended to be of anecdotal nature with low subject numbers; it lacked the rigor of randomization, placebo controls and blinding. In addition, little or no information was provided on the stimulation parameters and electrode placement sites utilized, thus making replication impossible.

The randomized controlled trial (RCT) is regarded as the gold standard in terms of determining the clinical efficacy of an intervention. An RCT is a trial in which patients are randomly allocated to different treatment groups, e.g. active treatment, placebo or control [12]. Blinding is a very important factor in the design of an RCT. This refers to whether or not the participants, those administering the interventions, and those assessing the outcomes are blinded to group assignment [13]. It has been suggested that studies that are not fully blinded can exaggerate the estimate of the effects of an intervention by up to 17% [14]. Similarly, the method by which subjects are assigned to their group is also a critical factor in an RCT; inappropriate randomization can exaggerate an intervention effect by up to 40% [14]. This is demonstrated by a systematic review by Carroll et al on the effect of TENS for postoperative care [15]. In 15 of the 17 RCTs included in this review, Carroll et al determined that TENS had no effect over placebo. However, the authors of 17 of the 19 non-randomized studies that were excluded from the systematic review concluded that TENS had a positive analgesic effect.

Systematic reviews offer a quick method of reviewing the clinical research on TENS. They should ideally provide an objective summary of the current literature on the chosen topic, but there are concerns regarding the methods involved in determining their outcome; de Bie advises that the "interpretation of the results of a systematic review should be done with a good deal of common sense and a healthy portion of suspicion" [16]. Systematic reviews involve the retrieval of relevant studies that have been selected according to certain inclusion criteria and using pre-defined criteria lists such as the Jadad, Delphi or Maastricht lists to score the quality of the study [17–19]. Items such as blinding, withdrawals, analysis and bias are subsequently used to rate the study's methodological quality. However, Verhagen et al compared the outcome of three criteria lists on a data set of 21 studies and highlighted several differences between them that affected their respective ranking of the studies [20]. The Table provides a summary of the key systematic reviews on the effectiveness of TENS published over the past several years. The authors of these systematic reviews have used the RCT as the inclusion criterion for their individual reviews. However, as many of the trials reviewed had considerable methodological problems, they received a low score on the criteria list used. These problems include insufficient reporting of treatment techniques, inadequate treatment time, lack of standardized outcome measures, and inadequate blinding and randomization techniques.

If we take a common pain condition such as low back pain (LBP), we would expect to find numerous studies

Table. Summary of transcutaneous electrical nerve stimulation (TENS) systematic reviews

Authors	Condition	Studies, n	Outcome
Brosseau et al [21]	Rheumatoid arthritis of the hand	3	- Conventional TENS resulted in no clinical benefit on pain intensity compared with placebo - Conventional TENS resulted in a clinical benefit on patient assessment of change in disease over acupuncture-like TENS
Cameron et al [22]	Dementia	8	Inconclusive
Milne et al [23]	Chronic low back pain	5	No evidence to support TENS
Osiri et al [24]	Knee osteoarthritis	7	Conventional TENS and acupuncture-like TENS effective over placebo
Proctor et al [25]	Primary dysmenorrhoea	9	High-frequency TENS more effective than placebo; low-frequency TENS no more effective than placebo
Price & Pandyan [26]	Post-stroke shoulder pain	4	Inconclusive
Carroll et al [27]	Chronic pain	19	Inconclusive
Carroll et al [28]	Labour pain	10	TENS had no significant effect
Carroll et al [15]	Postoperative pain	17	TENS had no benefit over placebo in 15 out of 17 RCTs

RCT = randomized controlled trial.

published on the efficacy of TENS. Yet, Milne et al could only include five eligible RCTs in their review of chronic LBP [23]. The reviewers indicated that there was a lack of data on type of application, treatment duration, and optimal frequencies and intensities. For example, the application of TENS varied greatly, ranging from one treatment per day for 2 consecutive days to three treatments a day for 4 weeks. The lack of standardized outcome measures used to report the effect of an intervention is a further inconsistency observed in TENS research. Osiri et al's systematic review on osteoarthritis and TENS included seven RCTs [24]. The range of outcome measures included assessments of pain, stiffness, joint circumference and muscle strength. Similarly, Carroll et al's review of 10 RCTs on labour pain highlighted the lack of consistency in the pain outcome measures that varied from a visual analogue scale to a 3- or 4-point pain scale and requirement for other analgesic interventions [28].

Conclusion

The concept of TENS has evolved from its early origins to become a popular modality in modern health care practice. Although the theoretical basis for electroanalgesia has been available since the 1960s, there is still a need for further investigation of the mechanisms of action underlying TENS analgesia. However, it is only through high-quality, adequately powered RCTs that the true clinical efficacy of TENS can be established.

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